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"煤拔头"工艺快速热解产物分布的实验研究

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摘 要:在煤拔头小试实验台上模拟煤拔头工艺,分别对黑龙江省依兰县3种典型煤(六级煤、造气入炉煤、油页岩)快速热解产物分布进行实验研究,研究得到了热解温度对焦油产率、煤气组分、煤焦油组分的影响规律。六级煤、造气入炉煤、油页岩焦油收率最高点的温度分别为481、519、514 ℃,焦油收率分别为13.58%、12.54%、4.23%;3种煤的H_2、CH_4产率均随T升高而升高;造气入炉煤、六级煤的CO产率均随T升高而升高,而油页岩的CO产率在490 ℃时达到最大,之后随T升高而下降;3种煤的CO_2产率受T影响均较小;六级煤在不同热解温度下,酚的衍生物和苯的衍生物产率较高;造气入炉煤在440 ℃时,长链烃约占焦油质量的50%。

关 键 词:煤拔头,煤热解,快速热解温度,焦油,煤气
中图分类号:TK16 **文献标识码**:A

引 言

以煤热解为基础的煤拔头工艺是以CFB锅炉的高温循环灰作为热源,在常压、中低温、无催化剂和氢气的条件下,用温和热解(低温热解600~650 ℃)的方式提取煤中的气体、液体燃料和精细化学品,热解后得到的半焦返回到CFB锅炉作为主要燃料燃烧发电,从而实现油、气、热、电的多联产,因此,也是煤基多联产技术的一种。该工艺集煤热解和燃烧分级转化为一体,作为一种煤炭高效洁净利用的方式日益受到人们的重视[1-4]。

按热载体的类型不同,国内外对煤的热解工艺研究主要集中于两个方向:固体热载体煤热解工艺和气体热载体煤热解工艺。与气体热载体工艺相比,固体热载体工艺有着明显优势[2]。国内外比较典型的气体热载体工艺主要有美国的COED工艺、美国的ENCOAL工艺以及波兰的双沸腾床工艺等,该工艺特点在于:传热效果好、升温速率高,产焦速率大,缺点在于:气体产物中N_2和CO_2含量高达50%~60%,气体产物热值较低,品质较差[1];国内外比较典型的固体热载体工艺主要有美国的Garret工艺、德国的LR工艺、美国的Toscoal工艺、前苏联的ETCH-175工艺、大连理工大学的DG工艺等。这些工艺特点在于:利用固体作为热载体,气体产物不受高温烟气的稀释污染,气体产物品质较好,热解产物后续处理困难较小,冷却系统负荷降低。

本研究以黑龙江省依兰县3种典型煤(油页岩、造气入炉煤、六级煤)为原料,在固体热载体煤热解小试实验台上对3种燃料快速热解产物分布进行试验研究,以期得到热解温度对热解产物、煤气组分及煤焦油组分的影响规律,为依兰煤拔头中试试验(CFB燃烧/煤热解多联产的工业过程)提供一定的依据。

1 试验部分

1.1 实验物料

实验所用的原料煤分别为油页岩、造气入炉煤、六级煤,均取自黑龙江省依兰县中煤能源黑龙江煤化工有限公司,其工业分析和元素分析如表1所示。原料粒径<1 mm,实验前在105 ℃下干燥2 h,选用平均粒径2.5 mm的石英砂作为热载体。

1.2 实验装置及流程

固体热载体煤热解实验装置及流程如图1所示。该实验装置主体部分主要由给料系统、电加热炉、热解反应器(螺旋混合反应器)、快速分离器、除尘装置和冷凝系统组成,实现了热载体的储存与加热、原料煤的输送、混合、反应及热解产物的气固分离和冷却。

其中,砂仓总容积约为0.048 m^3,石英砂流量为25 kg/h,流量误差要求控制在±1%范围内;煤仓总容积约0.013 m^3;电加热炉工作原理是利用镍铬

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电热丝来加热石英砂，总功率约为 11 kW。实验装置中采用的高温固体料阀结构如图 2 所示，料阀通过闸板的转动实现对物料流量的控制，当闸板与水平面之间夹角小于物料滑动角时，流量为零；当闸板与水平面夹角大于物料滑动角时，物料滑落至出料管，实验前用石英砂标定夹角与砂流量的关系，然后根据实验需要的石英砂流量设置闸板与水平面的夹角。此外，料阀的一侧设有手孔，遇到故障时打开手孔观察并处理故障。实验中系统所需给煤率为 2.5 kg/h，流量误差要求控制在 ±1% 范围内。实验中采用快速分离器对反应后得到的热解气（含焦油）、石英砂与半焦混合物进行分离，其结构如图 3 所示，快速分离器下部为锥形的圆筒，顶部分别设有进料口和热解气出口，热解气出口连接除尘装置。快速分离器中部设有固体料位计以便于检测快速分离器中固体料位高度，固体料位高度通过快速分离器下方料阀开度来控制。

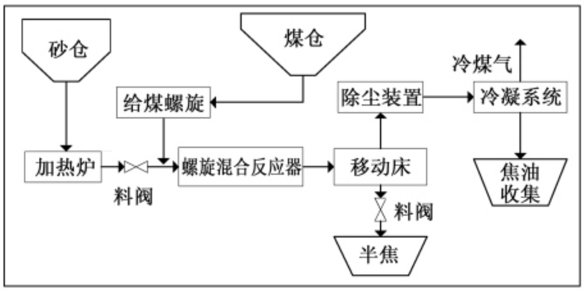

图 1　煤拔头小试实验台装置流程图

Fig. 1 Flow chart of a coal-topping miniature test rig

表 1　3 种煤的元素分析及工业分析（收到基）

Tab. 1 Elementary and industry analysis of three ranks of coal (as-received basis)

		六级煤	造气入炉煤	油页岩
工业分析/%	FC	48.0	32.6	5.6
	A	3.4	28.4	71.0
	V	42.1	33.9	21.9
	M	6.5	5.1	1.5
元素分析/%	C	54.9	46.5	17.0
	H	5.4	4.3	2.6
	O	28.6	14.1	6.9
	N	1.0	1.3	0.5
	S	0.2	0.3	0.5
	A	3.4	28.4	71.0
	M	6.5	5.1	1.5

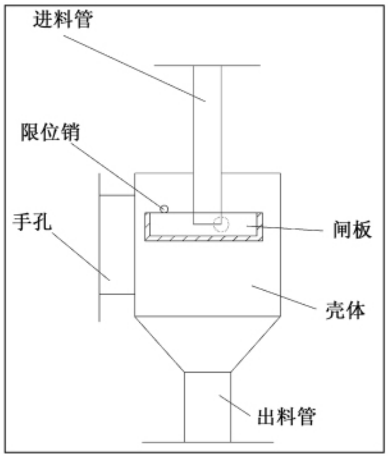

图 2　高温固体料阀结构图

Fig. 2 Structural drawing of a high temperature solid material valve

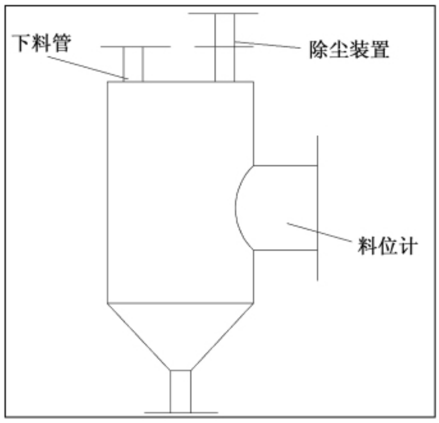

图 3　快速分离器结构图

Fig. 3 Structural drawing of a quick separator

实验中采用电加热方式将砂仓中的石英砂加热至指定温度，经料阀进入热解反应器，通过控制料阀的开度来调节高温石英砂的流量；煤仓中的煤粉由螺旋给煤机送入热解反应器，给煤量通过控制螺旋转速来调节；高温石英砂与煤粉在热解反应器中充分混合、热解；产生的热解气（含焦油）、石英砂与半焦混合物进入快速分离器；热解气从快速分离器上端排出，经过除尘装置捕集热解气（含焦油）中的固体颗粒后进入冷凝系统，在冷凝系统中高温热解气被快速冷却得到焦油，煤气经冷却降温后进入气体收集装置（本实验中采用气袋）；半焦混合物及石英砂则从快速分离器下部排出。根据实验要求，加热炉的温度设定为 700 ~ 950 ℃，除尘装置温度控制在 350 ℃左右。

1.3 产物分析

实验中，焦油用锥形瓶收集，对焦油的分析采用CP－3800（美国VARIAN公司生产）和300－MS型GC/MS分析仪分析。

分析条件为：以He为载气；初温设置为40℃，3 min后以4 ℃/min的速率加热到100℃，同样持续3 min，最后以6 ℃/min的速率加热到240℃，此时持续10 min。气体产物用气袋收集，通过湿式流量计计量，从气袋中取样并进行气相色谱仪分析。

2 实验结果与分析

2.1 热解温度对热解产物的影响

3种燃料在不同热解温度下焦油收率及煤气收率的变化规律如图4所示。（1）3种燃料在较低热解温度区间内，随着温度的升高，煤裂解加剧，总挥发分收率随之增加，半焦收率逐步降低。当热解温度上升到某一温度时，煤焦油收率达到最大值。（2）六级煤焦油收率最高时的温度为481 ℃，此时焦油收率为13.58%；造气入炉煤焦油收率最高时的温度为519 ℃，此时焦油收率为12.54%；油页岩焦油收率最高时的温度为514 ℃，此时焦油收率为4.23%。煤气收率则随着温度的升高而升高。（3）3种煤的煤气收率均随热解温度的升高而升高。（4）油页岩、六级煤、造气入炉煤分别在646、555、560 ℃时煤气收率达到3.015%、11.029%、6.804%。煤气增加的原因一是由于焦油二次裂解，二是半焦析出的剩余挥发性物质。焦油收率同时受到煤的自身裂解过程以及裂解后产生的有机质的二次裂解的双重影响。但是，焦油收率受煤的裂解影响较大，因此，在煤自身裂解阶段，焦油收率随热解温度的升高而升高[6~10]。

2.2 热解温度对煤气组分的影响

油页岩、造气入炉煤和六级煤热解时煤气组分的产率随热解温度的变化规律如图5～图7所示。提高热解温度，3种煤的H_2产率均增加；对于六级煤和造气入炉煤CO产率随热解温度的升高而升高，而对油页岩来说，CO产率在490 ℃附近达到了一次峰值，而后在温度上升至514 ℃的过程中，CO产率随着温度的升高而降低，此后CO产率一直随着温度的升高而升高；对于这3种煤，CO_2产率随着温度的变化甚微。

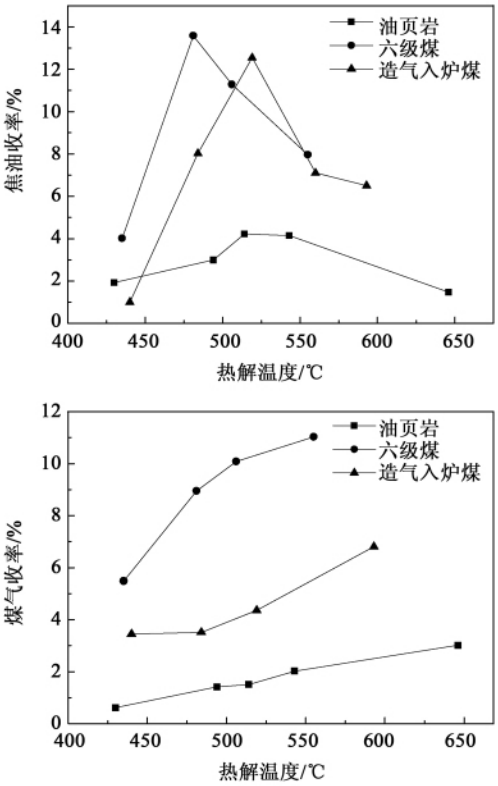

图4　3种煤热解时焦油收率及煤气收率随热解温度的变化规律

Fig. 4 Variation law of tar oil and coal gas production rate with the pyrolytic temperature when the three ranks of coal are being pyrolyzed

对于这3种煤，烃类气体中，CH_4的含量最高，且产率一直随热解温度的升高而升高。C_2H_6和C_3H_8产率对于不同煤种产率随温度变化规律有所相同，对于六级煤，C_3H_8、C_2H_6的最高峰均出现在481 ℃附近，而对于油页岩，C_3H_8、C_2H_6均在543 ℃附近达到最高值，此后，均随着温度升高而降低；对于造气入炉煤，C_3H_8、C_2H_6产率一直随温度升高而升高。

此外，对于这3种煤，C_2H_4和C_3H_6产率随热解温度变化规律基本相同，均随温度的升高而升高。通过观察研究，我们得到了3种燃料中C_2和C_3烃类气体收率规律：某一温度时，烷烃的产率达到最大值，之后随热解温度升高而下降，但是对于烯烃气体的产率则一直随热解温度升高而升高。3种煤在不同温度下热解时的液体产物中煤焦油所占份额如图8所示。由图可知，某一温度时，3种煤的煤焦油含量达到最大值，其它温度下，煤焦油含量反而降低。

观察图中 3 种原料煤焦油收率最高时对应的温度，我们发现，液体产物中焦油含量最高时的温度与该温度相吻合[11~18]。

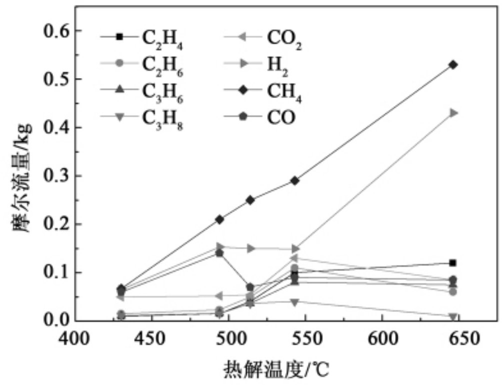

图 5　油页岩热解时煤气中各组分摩尔流量随热解温度的变化规律

Fig. 5 Variation law of the mole flows of various constituents of coal gas with the pyrolytic temperature when oil shale is being pyrolyzed

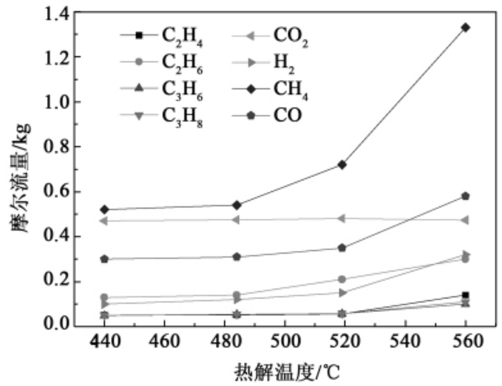

图 6　造气入炉煤热解时煤气中各组分摩尔流量随热解温度的变化规律

Fig. 6 Variation law of the mole flows of various constituents of coal gas with the pyrolytic temperature when coal fed into furnace for coal gas production is being pyrolyzed

2.3　热解温度对煤焦油组分的影响

实验中，我们分别收集了 3 种煤在不同热解温度下热解得到的焦油（此处仅列出较为有代表性的几个温度工况），通过 GC－MS（气相色谱－质谱联用仪）分析得到主要成分如表 2～表 4 所示。

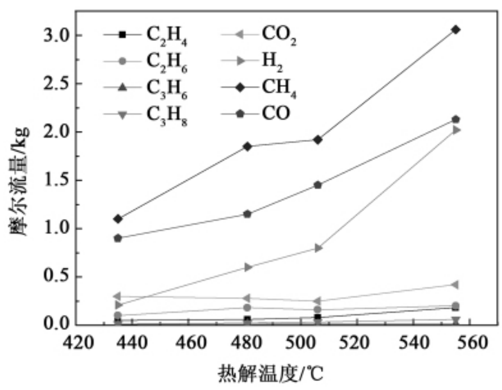

图 7　六级煤热解时煤气中各组分摩尔流量随热解温度的变化规律

Fig. 7 Variation law of the mole flows of various constituents of coal gas with the pyrolytic temperature when coal classified as grade No. 6 is being pyrolyzed

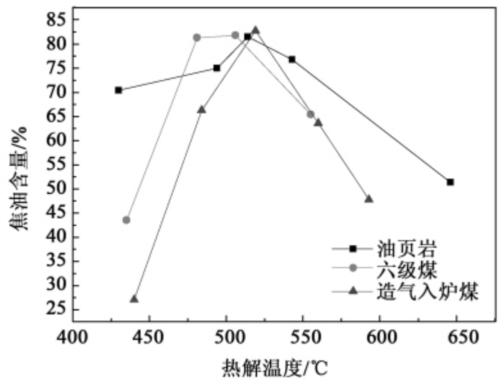

图 8　液体产物中煤焦油含量随热解温度的变化规律

Fig. 8 Variation law of the coal tar content of liquid products with the pyrolytic temperature

表 2　不同热解温度下六级煤热解焦油组成情况

Tab. 2 Composition of coal tar oil pyrolyzed by using coal classified as grade No. 6 at various pyrolytic temperatures

	所占份额/%		
	435℃	481℃	555℃
长链烃	44.205	23.157	7.294
酚的衍生物	17.231	16.423	26.806
苯的衍生物	7.513	12.512	23.031
稠环芳烃	5.136	14.698	19.037
非酚含氧化合物	25.904	31.695	23.054
其它	0.011	1.515	0.777

由表可知，对于六级煤，不同的热解温度下，非酚含氧化合物和酚的衍生物含量较高。对于造气入炉煤，440 ℃时焦油中长链烃约占一半，其次是非酚含氧化合物和酚的衍生物; 而 560 ℃时发生了较大的变化，含量最高的是酚的衍生物，约占四分之一，由于高温裂解的缘故，长链烃含量下降到 20%。对于油页岩，对比两种热解温度，我们发现，焦油中大部分为烷烃和烯烃[19-22]。

表 3　不同热解温度下造气入炉煤、油页岩热解焦油组成情况

Tab. 3 Composition of coal tar oil pyrolyzed by using coal fed into furnace for coal gas production and oil shale at variuous pyrolytic temperatures

	造气入炉煤所占份额/%			油页岩所占份额/%	
	440℃	560℃		430℃	543℃
长链烃	50.850	20.401	长链烃	55.464	38.867
酚的衍生物	9.191	25.000	烯烃	17.207	28.638
苯的衍生物	9.118	14.752	酚的衍生物	5.164	9.353
稠环芳烃	3.133	17.621	苯的衍生物	5.187	12.397
非酚含氧化合物	24.319	21.103	稠环芳烃	2.434	2.775
其它	3.389	1.123	非酚含氧化合物	14.544	7.839

3　结　论

通过实验，得出了 3 种煤的热解产物随热解温度变化规律，为以后依兰煤拔头中试实验积累了大量直接经验。在实验中，我们得到如下结论:

(1) 六级煤、造气入炉煤和油页岩分别在 481、519 和 514 ℃时，焦油收率达到最高，分别为 13.58%、12.54%和 4.23%;

(2) 3 种煤的热解产物中，在实验温度范围内，半焦收率随着热解温度的提高逐渐下降，煤气收率则持续上升;

(3) 焦油成份中酚的衍生物含量相对较高，而且随热解温度的升高而升高，555 ℃时，六级煤焦油成份中酚的衍生物含量高达 26.806%; 560 ℃时，造气入炉煤焦油成份中酚的衍生物含量高达25.0%; 543 ℃时，油页岩焦油成份中酚的衍生物含量高达 9.353%。

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（辉 编辑）

新技术、新工艺

H 级技术驱动热电联产装置

据《Gas Turbine World》2012 年 9 – 10 月刊报道，Siemens 已经从 Lotte 工程和建筑公司接到它的第五个 H 级动力装置技术订单，用于韩国大丘市 415 MW 创新的城市 CHP（热电联产）装置。该装置将建在韩国首都首尔以南约 240 公里处。

Siemens 将供应 1 台 SGT6-8000 H 燃气轮机、1 台 SST6-5000 汽轮机和冷凝器、1 台 SGen6-200 H 氢冷发电机、1 台 Benson 直流余热锅炉、电力系统和 SPPA-T3000 仪表和控制系统、以及部分辅机和辅助系统。

Siemens 也将负责该动力装置的全部设计并将监督装配和交工试运转。该公司也被授予 10 年的维护合同。

以天然气作为燃料，该装置的效率将超过 61%。在分区供暖的情况下，燃料利用效率将增加到超过 80%。试运转计划于 2014 年年末进行。

（吉桂明 摘译）

tration of the primary air ranges from 44.3% to 55.3% and that of the secondary air is between 43.2% and 60.2%. Under the condition of different air distributions, the conversion rate of the nitrogen in the coal to N_2O is in a range from 4.2% to 6.2% while that of the nitrogen to NO_x ranges from 4.2% to 8.3% and that of the sulfur in the coal to S_2O is between 48% and 62%. When the oxygen concentration of the primary air is 50.4%, that of the secondary air is 50.5% and the flow proportion of the secondary air is 40%, such a case is regarded as the optimum operating condition for lignite, under which the combustion efficiency will be 94.09%, the conversion rate of nitrogen in the coal to N_2O 5.4% and that to NO_x 4.2%. **Key words:** fluidized bed, O_2/CO_2, combustion, N_2O, NO_x

液体正庚烷在微细直管燃烧器中的燃烧特性研究 = Study of the Combustion Characteristics of Liquid N-heptane in a Tiny Straight Tube Type Burner［刊，汉］ ZHAO Jun-ying, LI Jun-wei, HUANG Jin-huai, et al (College of Astronautics, Beijing University of Science and Technology, Beijing, China, Post Code: 100081) //Journal of Engineering for Thermal Energy & Power. - 2013, 28(2). - 164 ~ 170

To learn the flame extinction and diffusion characteristics of liquid fuel in a micro space, various sleeve tubes and porous media were used. In a tiny straight tube, the diffused flame of heptane was experimentally studied. The research results show that with an increase of the flow rate of heptane, the stable location of the flame will gradually move to the outlet of the straight tube type burner, the flammable limits will first become wide at a high speed and then tend to be constant. To increase the number of the sleeve tubes can effectively expand the flammable limits and the structure of the sleeve tubes has a big influence on the flame stability and flammable limits. The more the number of the sleeve tubes, the smaller the heat quantity released from the burner. In addition, the location of the porous medium influences greatly the flame stability. When the nozzle of heptane is placed at the upper reaches of the porous medium or in it, the evaporation and mixing effectiveness of liquid heptane will be the best, thus obtaining a better oxygen-enriched combustion limit. **Key words:** tiny straight tube, n-heptane, combustion, flame stability, porous medium

"煤拔头"工艺快速热解产物分布的实验研究 = Experimental Study of the Distribution of Products Quickly Pyrolyzed in the "Coal-topping" Process［刊，汉］ JIN Qi-long, WANG Wen-yu, WU Shao-hua (Combustion Engineering Research Institute, Harbin Institute of Technology, Harbin, China, Post Code: 150001), LUAN Ji-yi (Mechanical Engineering Colleje, Jiamusi University, Jiamusi, China, Post Code: 154007) //Journal of Engineering for Thermal Energy & Power. - 2013, 28(2). - 171 ~ 176

On a small coal topping test stand, simulated was the coal topping process and experimentally studied was the distribution of products quickly pyrolyzed from the following three types of typical coal, namely, Grade No. 6 coal, coal fed into a furnace for coal gas production and oil shale rock originated from Yilan County of Heilongjiang Province. The

law governing the influence of the pyrolytic temperature on the coal tar productivity, coal gas constituents, coal tar constituents was obtained respectively: the temperatures corresponding to the highest yields of coal tar from the above-mentioned three types of coal were 481 ℃, 519 ℃ and 514 ℃ respectively and the coal tar yields were 13.58%, 12.54% and 4.23% respectively. The H_2 and CH_4 productivities of the three types of coal increased with an increase of the temperature while the CO productivity of the oil shale rock attained its maximum at 490 ℃ and then decreased with an increase of the temperature. The carbon dioxide productivities of the three types of coal were all influenced little by the temperature. At various pyrolytic temperatures, Grade No. 6 coal had relatively high productivities of hydroxybenzene and benzene derivatives. When the temperature was 440 ℃, the long chain hydrocarbons of the coal fed into the furnace for coal gas production approximately took up 50% of the coal tar in weight.
Key words: coal pyrolysis, pyrolytic temperature, coal tar, coal gas

探讨用于气固多相流检测的广义动态重建算法 = Exploratory Study of the Generalized Dynamic Rebuilding Algorithm for Testing and Measuring a Gas-solid Multi-phase Flow [刊, 汉] WANG Ze-pu, LIU Shi, ZHOU Lei (College of Energy Power and Engineering, North China University of Electric Power, Beijing, China, Post Code: 102206), CHEN Jiang-tao (Beijing Subcompany, China Tianchen Engineering Co. Ltd., Beijing, China, Post Code: 100029) //Journal of Engineering for Thermal Energy & Power. – 2013, 28(2). –177~181

Through monitoring the flow speed and rate of a gas-solid two phase flow, the flow characteristics of the fluid transmitted was clarified and the pneumatic transmission process was successfully performed. The capacitance topography technology is regarded as one of technologies for detecting a gas-solid two phase flow and the key lies in its image rebuilding link. Through choosing a proper image rebuilding algorithm, one can reversely deduct the distribution characteristics of the fluid transmitted in a section. To improve the rebuilding image quality of the ECT system and enhance the accuracy of the detection technology, presented was a generalized dynamic image rebuilding algorithm integrating the space restriction, time restriction and reverse deduction information of the fluid flow. By analyzing and comparing the numerical test and the conventional image rebuilding algorithm, the authors believe that the image structure rebuilt by using the algorithm in question should be clearest. The test showed the pulverized coal and ash pneumatic transmission process as reversely deducted by using the algorithm in question. Both coal and ash obviously embodied the advantage of the dynamic rebuilding algorithm. **Key words:** electric capacitance topography (ECT), generalized dynamic rebuilding algorithm, gas-solid two-phase flow, annular flow, bubble flow

粒子群优化 BP 神经网络飞灰可燃物预测建模 = Modeling for Predicting the Flammable Content of Fly Ash Base on a Particle Swarm Optimized Back Propagation Neural Network [刊, 汉] LU Tai, GUO Zhi-qing (College of Energy Power and Engineering, Northeast University of Electric Power, Jilin, China, Post Code: 132012) //Journal of Engineering for Thermal Energy & Power. –2013, 28(2). –182~186